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Citation: Physics Today **9**, 7, 10 (1956); doi: 10.1063/1.3060021
View online: http://dx.doi.org/10.1063/1.3060021
View Table of Contents: http://physicstoday.scitation.org/toc/pto/9/7
Published by the American Institute of Physics

Physics Tonight

By J. Robert Oppenheimer

An address presented before the American Institute of Physics as part of the AIP's 25th Anniversary Session on the general topic "Anticipations", held February 2, 1956, in New York City.

PHYSICISTS are involved in a wonderfully diverse and varied set of enterprises, not simply and necessarily related. Your speaker is not distinguished by the development of his imagination; almost everything that happens amazes him. I shall not try to give a general landscape of all that physicists are up to. It ranges from the magnetohydrodynamics of interstellar matter to nuclear alignment at low temperatures; it ranges from the giant rocket to transistors, and to instruments for detecting valuable minerals in the ground; it ranges from automation to the coding problem of genetics; it ranges from teaching doctors and engineers and soldiers, and even ordinary men, to advising the heads of state.

I shall speak to three separate themes, illustrative of this diversity, that may be samples. One has to do with the physicist as teacher, and a serious problem in communication. One has to do with the physicist as citizen, and the changes that his works have brought about in the arts of war. The first and the main sample has to do with physics itself, and the physicist as discoverer.

PROGRESS in physics is always marked by two complementary traits, one centripetal and one centrifugal. We always try, by the use of new techniques, instruments, technology, and ideas, to transcend past experience, to find out something new, and to penetrate into aspects of the physical world hitherto hidden or implicit. This is the side that has adventure in it. It is the side for which the great accelerators and the ingenious detectors are devised, that give a touch of romance and adventure and novelty to our work.

Yet at the same time we try to find the elements of unity and of order in the new experience, and in its connections with the old. It is true that we are pluralists. We maintain, rightly and stoutly, that any part of physics is just as good, just as much a reward to the intelligent, just as worthy as any other.

But there is another side to it; physics has remained rather more united than almost any other part of human thought. It has been possible to reduce immense, varied experience to a few, simple, rather necessary, not too empirical themes and principles. When we had courage we used to call them laws. Remembering what other meanings law can have, we are hesitant to call them laws.

We often deprecate the majesty and power of the order that pervades the physical world, because we know that it is not all comprehended, is subject to change without notice, and that at any given moment our attention and our wonder are devoted primarily to what we do not understand, to the puzzles. You have only to think of the history of physics, of Newtonian mechanics, or Maxwell's theory, or, in this century, of the immense syntheses of the theories of relativity, or of atomic mechanics. In these there are traits of simplicity, of unity, and of necessity, and the vastest and most disparate experience is comprehended within a few general ideas and principles.

Today, in what is called in the trade particle physics —and here I would include mesodynamics and at least some aspects of field theory—we are searching for this order, and we are very far from seeing it. We have a vast jumble of odd dimensionless numbers, none of them understandable or derivable, all with an insulting lack of obvious meaning. Just in the class of objects that live long enough to deserve the name of particle there are the light mesons, the K-mesons, at last the antinucleon, and the hyperons. This should not be a talk to the special problems that at the moment seem most pressing of solution: the relation of the τ-meson and the θ-meson; why the antiproton interacts with such a large cross section with nuclei; whether we can understand the scattering of pions in S states. There are greater mysteries.

We have a maze of findings: the masses of the semistable particles, their lifetimes, their reactions, their numerous and striking selection rules. In some ways this field may remind us of the quantum theory of atoms as it was in the earlier years of this century; but we have not found that single key to the new physics that Planck discovered at the turn of the century, nor anything analogous to Bohr's postulates. Above all, we do not have the great guidance of the correspondence principle to relate familiar physics that we understand with the phenomena now newly discovered.

INDEED, in ordering the discoveries in this field we have three sure guides and one uncertain one: small fingers of light in the darkness, imperfect analogies, by whose correction and refinement we may hope for understanding. It is not wrong that we use analogies. There can hardly be any other way than to try to talk about a new situation in terms which have been adequate to an older one, aware that we are making a mistake, but trying to learn from nature what the mistake is.

One of these fingers of light is the nonrelativistic quantum mechanics. One uses this in the model exploited by Chew, for the study of the interaction of mesons and nucleons. It rests on the fiction, which obviously is not going to last forever, that the mass ratio of nucleon to pion, which is in fact about seven, is infinite.

The second is the theory of weakly interacting fields, of which the most perfect and most beautiful example is quantum electrodynamics, just in its present approximate state. It is so perfect that for positronium I suppose we have rightly the feeling that there are only two kinds of mysteries left. One is that the charge and the mass of the electron are numbers that mean nothing to us, that we have to read from experiment. The other is that there are some really academic fine points that we may not know enough about. Thus it is possible that higher order Fermi processes somewhat modify the interaction of electron and positron. It is certain that the existence of mesons and nuclear matter modifies the electromagnetic field. We know a little of this, but perhaps not in all detail. We hardly can be sure, not knowing what mesons exist. We even know that somewhere in this picture gravity probably plays a part. But these are all of such extraordinary remoteness and smallness that we have an almost closed theory of positronium, as closed as it is healthy for anything to be in this world.

J. Robert Oppenheimer, professor of physics and director of the Institute for Advanced Study in Princeton, is a former president (1948) of the American Physical Society.
(Photo by Gertrude Samuels—PIX)

It is even something of a paradox that the weak interactions introduced by Fermi to describe radioactive processes give us one of the few quantitatively adequate instruments of description, and that the strong, more obvious forces elude us.

A third tool is our understanding of the connection between the invariance of physical systems, and the constants, or almost-constants, of the system's behavior—its selection rules. We have begun to see that some of the most striking of these symmetry or invariance properties lie outside the Lorentz group, and the simple rules of charge symmetry and of the identity of elementary particles.

The fourth tool, and a very powerful one it is, is the application of relativity and its pronouncements about causal behavior to the theory of fundamental particles. It is a powerful tool, but it is not certain; for we are not convinced that we as yet understand how to formulate the requirements of relativity in domains of experience in which our familiar ideas of space and time are not obviously or necessarily applicable.

WHAT sort of questions can we ask about the order that we do not have and are seeking? I can think of at least three: Will this be an atomic theory, in the basic sense that the number of long-lived fundamental particles is finite? Shall we find that, as we study with higher and higher energy impacts and higher and higher resolving power, we come to an end of the relatively stable components of matter? The experience of the last five years can be read both ways. Very much new has been found; but it seems a small lot, and we do not know whether there is another installment coming.

This question, as has long been recognized, may be closely related to the question of whether we can in fact define the state of affairs in arbitrarily small intervals of space and time. The reason is that if one has an infinite regress of more massive objects that last indefinitely long compared to their proper times, it would appear that they could be used rather naturally for the measurement of smaller and smaller intervals. If there are no such particles, then the definition of spaciotemporal relations and the definition of fields is at least not a direct extension of what we have known in classical and quantum theory.

The second question rests on the first. If we are through, or will one day soon be through with the discovery of fundamental particles, will we also be through with the discovery of the laws of their behavior? Hitherto, the changes in physical law as we go to higher energy and smaller distance have usually been characterized by the emergence, or the emerging importance, of new objects. Is a new regime that is qualitatively different to emerge when we come to still higher energies, even though there are no stable particles, or quasistable particles, characteristic of that energy? There is no necessary answer to this question, even if we accept the finiteness of the fundamental group of particles. There are, among others, two probably related reasons: One is that the particles are of a great but only finite and limited stability. Their instability is measured by the mysteriously small number which characterizes the Fermi interactions, which points in an obscure way to the even smaller number characterizing gravitational forces. Do these define enormously higher energies than those now under study, where novelty again appears, novelty relevant to the character of the atomic world? Of course they do define enormously higher energies. We do not know whether that means that a new set of laws and a new set of phenomena will become manifest, and we do not know whether it is relevant to the great puzzles with which we are living today.

The third question rests even more heavily. Will this world, with its variety, its un-understood numbers, ever really yield to an ordered description, simple and necessary? Will our future students be able to explain the mass ratios, the coupling constants, the selection rules, as necessary consequences of the physical principles of the subnuclear world; or will these remain empirical findings, to be measured with greater and greater accuracy, and recorded in tables that every physicist must memorize or carry about with him? Surely past experience, especially in relativity and atomic mechanics, has shown that at a new level of explanation some simple notions previously taken for granted as inevitable had to be abandoned as no longer applicable. Surely we are fully prepared not to regress in this, not to find that in this new domain the generalization symbolized by Planck's constant and the velocity of light are suddenly no longer there. On the contrary, we are prepared for a new and at first probably almost unrecognizable kind of explanation. Always in the past there has been an explanation of immense sweep and simplicity, and in it vast detail has been comprehended as necessary. Do we have the faith that this is inevitably true of man and nature? Do we even have the confidence that we shall have the wit to discover it? For some odd reason, the answer to both questions is yes.

PHYSICISTS not only invent and discover; they also explain. On the one hand we are teachers, increasing the number and, we hope, the competence of our own profession. There is for us at least one great problem that, in my opinion, is relevant to the now very prominent question of the adequacy of our profession, both in talent and in number, to the needs of the time and of our country.

It is true that here much could, and some should, be said of many of the practices by which we waste ourselves and our colleagues, and the treasure of their genius and training. I do not have in mind so much the Federal security system, though there are too many people here who know its sorrows and its evils to ignore it. I have in mind quite practical things, for the shortage of people is largely in practical undertakings. The diversion of scientists to administration, the terrible problems of largeness in organization, lack of adequate assistance, the committees on committees, these could all be better than they are, could by being better greatly enrich the productivity, the elegance, the march and sweep of science. There is moreover, and this is far graver, in many practical undertakings, a characteristic deep fog in policy, a tendency massively to pursue premature and trivial and irrelevant undertakings, that is frightfully wasteful of great resources. There is, as all of us who live near universities know, the monstrous anachronism of our attempting to educate by lecture.

The problem of communication is also relevant to our relations with our time and our culture, with the overwhelming majority of our fellows who are not physicists, and for whom we would wish that they could know something of our work, and have some honest pleasure in it. I may not deal with this theme with anything like the majesty and sweep that Dr. Stratton brought to it.* I would add one comment, which overcame me as I listened with some anguish to what he said. For there is an old truth that we cannot teach what we do not know: I fear that he has characterized as an educational crisis, a default in transmission to a new generation, what is in fact a deeper crisis, a default in our own understanding. This crisis is deep in the mind of every thoughtful scientist. What can we do better to maintain the health and the firmness of our civilization? How can we let the beauties, the excitement, the order, the love of science play some helpful part?

Every scientific advance, past or contemporary, has two traits: it is an enrichment of technique; it enables us to do what we could not do before, or to do it better: it is knowhow. It is also, on the other hand, the answer and formulation of questions long agitating man's curiosity, something to contemplate, in Peirce's words, "the demi-cadence which closes a musical phrase in the symphony of our intellectual life", a glimpse of harmony and order, a thing of beauty: it is knowledge.

As physics grows, and there appears to be more and more to learn, the problem of reconciling knowhow and knowledge grows more difficult and more urgent. We do solve it in one context. In the last years of graduate study, in the years following those of postdoctoral study, knowhow and knowledge are not each other's enemies, but each other's complements. There students are allowed to forget almost all there is in the world except the problems on which they are working. They are then in action as apprentices. They see the relevance of technique to understanding, and, if we or they are any good at all, they are touched with the light and wonder at finding out something new.

We tend to teach each other, except in the golden years of graduate and postdoctoral study and apprenticeship, more and more in terms of mastery of technique, losing the sense of beauty and with it the sense of history and of man. On the other hand, we tend to teach those not destined to be physicists too much in terms of the story, and too little in terms of the substance. We must make more humane what we tell the young physicist, and must seek ways to make more robust and more detailed what we tell the man of art or letters or affairs, if we are to contribute to the integrity of our common cultural life.

PHYSICISTS are not only inventors and discoverers and teachers: they are busy in almost all the practical undertakings of a highly technical society, making available to men power, material, information, and order.

I will take one field where our works have made changes of great portent for man's history. We have changed the instruments, and therefore in large measure the nature, of war. What this was to mean for our future has been in part vivid and clear for a long time now to many of those who worked during the second world war to make available the new resources. I think especially of Bohr, but he was far from being alone. Despite the "peace of mutual terror", despite "deterrence" and "retaliation", despite the growing apparent commitment to the thesis that global or total war has become "unthinkable", the full import of the new situation is surely not clear today. This is in part because there tends to be between the intention and the pronouncements of statesmen and of governments, and what in fact happens, an often tragic mismatch; it is even more because of the larger truth that civilizations themselves achieve their greatest triumphs, not by their avowed purpose, intent, and dedication, but almost by inadvertence.

I know how many of you devote much of your heart and life not only to the explanation of the technical possibilities, but to weighing the probable course of future development, and the alternatives of policy. Yet the last decade has brought one change that we must welcome. In a measure that is in the nature of things neither complete nor adequate, the new situation has been explained to the makers of policy in particular, and to people in general. The labors of physicists in explanation and in prophecy are not and cannot be ended; and there is no standing Joint Committee on the World's Salvation to which they can abdicate their concern. Yet by now the problem of living with the new dangers and the new hopes is where it belongs: with the public and its officers, the governments. Let us be sure that by our effort and our clarity we always keep it there.

THESE three themes that I have touched could hardly be more disparate. I see no logical or necessary relation between them. The majority of us is concerned with only one or another, or with yet a different room in the vast house of physics. They are connected for us not through logic, but because there are among us men who have an interest in more than one. This is the unity of our profession, as, in my opinion, it must be typical of the unity of contemporary culture and even life. The American Institute of Physics and its founder societies are the benign framework for bringing together not only the specialists, but those among you who, by bearing in themselves more than one passion, provide the basis of our community.

* J. Stratton, "Science and the Educated Man", *Physics Today*, April, 1956. This lecture was given before the same session of the American Institute of Physics as the talk printed here.